RADIOCARBON, Vol 41, Nr 2, 1999, p 199–213

RUDJER BOŠKOVIĆ INSTITUTE RADIOCARBON MEASUREMENTS XIV

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INTRODUCTION

In this report we present dating of several large series of samples mostly collected in Croatia: 1) Iron Age and medieval samples excavated in Zagreb, 2) speleothems from a karst site in central Croatia, 3) shallow sediments from the Plitvice lakes, 4) tufa from the Krka River, 5) sea sediments from the Adriatic Sea, and 6) tree rings from Hungary, Croatia and Slovenia. Sample preparation and proportional counter technique are essentially the same as reported earlier (Srdoč et al. 1971). Processing of data has been computerized (Obelić 1989).

Age calculations follow the conventional protocol based on the Libby half-life (5570 ± 30 y), using AD 1950 as the reference year. Ages and standard deviations (1 σ error) of samples were adjusted for stable isotope fractionation according to the methods of Stuiver and Polach (1977). Calibrated ages (for archeological samples only) were calculated by using the program OxCal v.3.0 (Ramsey 1995, 1998) with 1σ error (confidence level 68.2%). When several calendar age ranges were obtained, probability for each interval is given. Probabilities of <5% are omitted. Range intervals are rounded. ^{14}C contents of geological samples are expressed in pMC, and of environmental samples in $\Delta^{14}C$.

ARCHAEOLOGICAL SAMPLES

Croatian Museum of Natural History Series

Wood fragments of a beam from remnants of a wooden house buried in the yard of the Croatian Museum of Natural History, Zagreb Upper Town, Croatia (45°50′N, 16°0′E), 150 m above sea level (asl). Collected and submitted in May 1992 by M Šmalcelj, Department of Archaeology, University of Zagreb.

Comment: (MŠ) Conservation works in museum's yard. Expected age: 15th to 17th century.

Z-2398. Croatian Museum of Natural History 1 **200 ± 130**
Wood fragment of a beam from western part of the house, 1.20 m depth (cal AD 1630–890, 58.9%; AD 1910–1950, 7.3%).

Z-2399. Croatian Museum of Natural History 2 **220 ± 120**
Wood fragment of a beam inside the house, 1.20 m depth (cal AD 1510–1590, 13.4%; AD 1620–1700, 17.5%; AD 1720–1880, 24.4%).

Z-2400. Croatian Museum of Natural History 3 **400 ± 90**
Wood fragment of the floor, 1.50 m depth (cal AD 1430–1530, 42.1%; AD 1560–1640, 26.1%).

Z-2401. Croatian Museum of Natural History 4 **240 ± 90**
Wood fragment of a beam outside the house, 1.80 m depth (cal AD 1510–1690, 43.1%; AD 1730–1820, 21.5%).

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Municipal Museum Series

On the occasion of the 900th anniversary of Zagreb, the capital of Croatia, extensive archaeological excavations were performed at the historical complex of the present-day Municipal Museum in the Upper Town of Zagreb, 161 m asl. The museum is located at the northeast corner of the Upper Town and includes Popov Toranj (Priest's Watchtower), the former Convent of St Clare built in the 17th century (now the museum), and the Old Town granary. Samples were taken from the inner part and surroundings of the former Convent of St Clare. The area has been inhabited since prehistoric times (Iron Age), and was part of wooden fortifications during the Middle Ages. Minor differences in ^{14}C ages between the previously published results (Obelić et al. 1995) and the present ones are due to the additional measurements. Samples were collected and submitted by M Šmalcelj.

A) Parlatorium

Boards below the present floor of the *parlatorium* of the convent.

Z-2448. Parlatorium 1 **2085 ± 100**
Charcoal found beneath a Hallstatt bowl, quadrant P-4/C-2 (cal 360–310 BC, 7.8%; 210 BC–AD 20, 60.4%).

Z-2449. Parlatorium 2 **2040 ± 110**
Charcoal from the same cultural layer as above, quadrant P-4/A-4 (cal 200 BC–AD 80, 68.2%).

Comment: (MŠ) Estimated archaeological age: La Tène.

Z-2450. Parlatorium 3 **1775 ± 85**
Same as above, but the age is not confirmed by archaeological finds; quadrant P-4/C-3 (cal AD 130–340, 68.2%).

Z-2451. Parlatorium 4 **1770 ± 85**
Same as above, quadrant P-4/B-3 (cal AD 130–350, 68.2%).

B) Convent Hall

Remains of shallow sod houses overlain by dwellings with stone basements and stone hearths in the eastern part of hall of the convent.

Z-2452. Convent Hall 1 **2340 ± 115**
Fragment of dwelling post near fireplace; quadrant P-4/A-4 (cal 800–200 BC, 68.2%).

Z-2453. Convent Hall 2 **2100 ± 85**
Fragment of dwelling post, layer 40 cm above fireplace, quadrant A-B/1-3 (cal 360–310 BC, 8.7%; 210 BC–AD 1, 59.5%).

Z-2454. Convent Hall 3 **2375 ± 105**
Charcoal from fireplace, quadrant A-21 (cal 770–680 BC, 17.3%; 660–630 BC, 5%; 560–380 BC, 42.3%).

Comment: (MŠ) Dated to an older Hallstatt phase.

Z-2455. Convent Hall 4 **1990 ± 100**
Charcoal from the remnants of a house, quadrant A-17 (cal 120 BC–AD 120, 67.2%).

Z-2456. Convent Hall 5 **2110 ± 100**
Charcoal from the remnants of a house, quadrant A-17 (cal 360–290 BC, 12.8%; 260–30 BC, 55.4%).

Z-2457. Convent Hall 6 **2590 ± 130**
Charcoal from the remnants of a house, quadrant A-16-17 (cal 900–750 BC, 30.9%; 720–520 BC, 37.3%).

Z-2458. Convent Hall 7 **2505 ± 80**
Charcoal from the remnants of a house, quadrant B-12 (cal 800–740 BC, 12.5%; 730–520 BC, 55.7%).

Z-2459. Convent Hall 8 **2290 ± 105**
Charcoal from the remnants of a house, overlying pit where sample Z-2457 was found, quadrant A-14 (cal 520–190 BC, 68.2%).

C) Eastern Convent Wing

Samples below the floor of the eastern wing of the convent.

Z-2460. Eastern wing 1 **1745 ± 135**
Burned oak from the remnants of a house, quadrant F-9.

Comment: (MŠ) Sample stratigraphically associated with La Tène, although not supported by ^{14}C dating (cal AD 110–430, 68.2%).

Z-2461. Eastern wing 2 **1630 ± 105**
Round logs from the remnants of a house, quadrant G-14.

Comment: (MŠ) Stratigraphically associated with La Tène, although not supported by ^{14}C dating (cal AD 260–290; 6.8%; AD 320–550, 61.4%).

Z-2463. Eastern wing 3 **2255 ± 110**
Burnt trunk lying over the fireplace, quadrant A-14 (cal 400–160 BC, 65.9%).

D) Promenade Vrazovo Šetalište

Burnt timber from the remains of the rampart buried along the slope following the eastern wing of the convent to the present-day promenade Vrazovo šetalište. The burned layer consists of up to 50 cm of clay (average thickness 30 cm), overlying a timber foundation. The foundation seems to have been burned deliberately to fire the clay and provide a solid base ca. 6 m wide for an additional clay fill into which the wooden posts of a palisade were driven. The most probable period when the trees were felled was between the 4th and 3rd century BC (Obelić et al. 1995).

Burnt Timber

Z-2482. Vrazovo šetalište 1 **2220 ± 85**
Quadrant K/L-37/38 (cal 390–190 BC, 68.2%).

Z-2483. Vrazovo šetalište 2 **2350 ± 85**
Quadrant N-39; (cal 760–680 BC, 14.8%; 550–360 BC, 49.3%).

Z-2484. Vrazovo šetalište 3 **2215 ± 110**
Quadrant K-38 (cal 400–160 BC, 65.7%).

Z-2485. Vrazovo šetalište 4 **2310 ± 100**
Quadrant K-38 (cal 550–200 BC, 65.5%).

Z-2486. Vrazovo šetalište 5 **2250 ± 75**
Quadrant K/L-37/38 (cal 400–340 BC, 21.3%; 320–200 BC, 46.9%).

Z-2487. Vrazovo šetalište 6 **2215 ± 90**
Quadrant H-38 (cal 390–190 BC, 68.2%).

Z-2488. Vrazovo šetalište 7 **2300 ± 105**
Quadrant F-41/42 (cal 530–190 BC, 68.2%).

Z-2490. Vrazovo šetalište 8 **2400 ± 140**
Quadrant H-38 (cal 770–390 BC, 68.2%).

E) Chapter House

Outer tree rings of boards, apparently used as roof shingle, thrown into a trench in the 15th century during the reconstruction of the Chapter house, which is located next to the *parlatorium*.

Z-2280. Chapter house 1 **300 ± 75**
Fragment of board No. 12 (cal AD 1480–1660, 68.2%).

Z-2285. Chapter house 2 **260 ± 105**
Fragment of board No. 26 (cal AD 1480–1690, 52.4%; AD 1740–1810, 15.8%).

Z-2286. Chapter house 3 **325 ± 80**
Fragment of board No. 10 (cal AD 1480–1650, 68.2%).

F) Popov Toranj (Priest's Watchtower)

Wood (*Quercus* sp.) from a beam, containing 50 tree rings, from ramparts located at the northwest corner of the convent complex.

Z-2369. Popov toranj 1 **765 ± 50**
Ten outer tree rings, top of the central post (cal AD 1220–1280, 68.2%).

Z-2371. Popov toranj 2 **540 ± 80**
Ten innermost tree rings, same post as above (cal AD 1300–1360, 31.8%; AD 1380–1440, 36.4%).

G) Mediaeval Trenches

Samples from inner and outer trenches of the rampart.

Z-2405. Trench 1 **480 ± 115**
Fragments of twigs buried in mud from profile of arch No. 2 (cal AD 1310–1360, 15.3%; AD 1380–1520, 47.2%, AD 1590–1630, 5.7%).

Z-2406. Trench 2 **230 ± 90**
Wood buried in mud (cal AD 1510–1600, 18.2%; cal AD 1620–1700, 20.3%; cal AD 1720–1820, 24.8%).

Z-2407. Trench 3 **540 ± 80**
Animal bone buried in mud (cal AD 1300–1360, 31.8%; AD 1380–1440, 36.4%).

Z-2408. Trench 4 **170 ± 85**
Fragment of board from the arch No. 2, trench No. 2 (cal AD 1650–1700, 13.6%, AD 1720–1880, 33.6%; AD 1836–1880, 12.5%, AD 1910–1950, 8.5%).

Z-2409. Trench 5 **605 ± 80**
Fragment of board (*Quercus* sp.) from the rampart's planking between pillars No. 4 and 5 (cal AD 1290–1400, 68.2%).

Z-2410. Trench 6 **440 ± 80**
Fragment of wooden stick from Quadrant 29a, probably reconstruction of outer trench (cal AD 1400–1520, 57.6%; AD 1590–1630, 10.6%).

Z-2411. Trench 7 **580 ± 90**
Fragment of damaged wooden door frame from the entrance to the trench next to the stairs, between pillars No. 14 and 15 (cal AD 1290–1420, 68.2%).

Z-2412. Trench 8 **795 ± 85**
Fragment of wooden door from the entrance to the trench, next to the stairs, between pillars No. 14 and 15 (cal AD 1150–1290, 62.4%). Tree ring counting resulted in AD 1183–1289. (Durman, personal communication 1994).

Z-2413. Trench 9 **430 ± 85**
Fragment of a broom *(Sorghum)* from the entrance to the trench next to the stairs (cal AD 1400–1530, 52.3%; cal AD 1580–1630, 15.9%).

H) Convent Cloister

Wood samples from the cloister of the former convent. *Comment*: (MŠ) Expected age: 16th century.

Z-2414. Cloister 1 **260 ± 80**
Wood fragment from quadrant A-10, Pit 2 (cal AD 1500–1680, 52.8%; AD 1740–1810, 15.4%).

Z-2415. Cloister 2 **375 ± 85**
Wood fragment buried in mud from Pit 3 (G-1) (cal AD 1440–1530, 37.6%; AD 1560–1640, 30.6%).

Z-2416. Cloister 3 **280 ± 80**
Wooden remains of a pillar buried in mud at W profile from Pit 2, corner of the cloister (cal AD 1480–1670, 65.0%).

Z-2417. Cloister 4
Wood buried in mud below the colored eggshells, Pit 1 (cal AD 1480–1640, 68.2%).

Z-2425. Cloister 5 **120 ± 80**
Straw from Pit 3 (cal AD 1680–1750, 23.1%; AD 1800–1940, 45.1%).

GEOLOGICAL SAMPLES

Hvar Island Series

Wood from seabed off Hvar Island, west of Korčula Island in the Adriatic Sea, southern Croatia. Seawater depth 74 m. Collected and submitted March 1994 by M Juračić, Geological Department, University of Zagreb.

Z-2507. Wood from seabed, depth 60–65 cm **18,700 ± 400**

Z-2506. Wood from seabed, depth 120–125 cm **22,500 ± 600**

Adriatic Sea Series

Inorganic sediments from several boreholes from north Adriatic Sea, 74 km northwest from Pula (44°52′N, 13°51′E), Istria, southwest Croatia. Investigation of natural gas reserves in the Adriatic Sea. Submitted April 1991 by E Prohić, Faculty of Natural Sciences, Zagreb.

Table 1 Adriatic Sea series

Sample nr	Borehole	Depth (m)	pMC
Z-2333	J-1	725.0–725.5	8.0 ± 0.8
Z-2334		725.5–726.0	7.0 ± 0.8
Z-2335	J-4	761.2–761.7	26.3 ± 0.9
Z-2336	J-15/2	854.0–854.5	20.5 ± 1.3
Z-2337		928.5–929.1	3.3 ± 1.2
Z-2358		930.5–931.1	8.4 ± 0.6
Z-2338		931.5–932.0	9.0 ± 0.8
Z-2339	J-15/3	929.0–929.7	12.0 ± 0.9
Z-2340		934.0–934.5	4.6 ± 0.5
Z-2341		936.0–936.5	7.5 ± 0.8
Z-2342	J-18/3	1019.5–1020.1	8.9 ± 0.9
Z-2343	J-18/9	606.0–606.5	12.8 ± 0.8
Z-2344		609.0–609.8	8.2 ± 0.9
Z-2345		841.0–841.6	10.7 ± 1.1
Z-2346		1060.0–1060.8	3.9 ± 0.8
Z-2347	Ivana-3	708.0–708.8	9.0 ± 1.0
Z-2348		710.0–710.8	4.5 ± 0.8
Z-2349		712.0–712.7	2.8 ± 0.8
Z-2350		715.0–715.6	<0.5
Z-2351		717.0–717.5	3.0 ± 0.4
Z-2352		718.0–718.4	3.3 ± 0.6
Z-2353		722.0–722.5	3.4 ± 0.8
Z-2354		723.5–724.2	<0.5
Z-2355		728.5–728.9	14.1 ± 1.1
Z-2356		729.5–730.4	8.6 ± 1.0
Z-2357		733.5–734.3	15.4 ± 0.8

Tounj Series

Phreatic speleothems from Tounj Cave near Tounj (45°15′N, 15°20′E), Dinarides, central Croatia. Samples collected from laminated speleothem at various distances from the bedrock. (Babić et al. 1996). Collected and submitted October 1992 by D Lacković, Faculty of Natural Sciences and Mathematics, Univ. Zagreb.

Comment: (NH) ^{14}C age does not correlate with stratigraphic position. Possible explanation: non-uniform contamination by detrital carbonate mud produced by weathering of Mesozoic carbonates.

Krka River Series

Tufa from Krka River between Knin (44°02′N, 16°11′E) and Skradin (43°49′N, 15°55′E), 56 km long, southern Croatia. The Krka River flows in the karst region of southern Dinarides and empties into the Adriatic Sea (Friganović 1984). Tufa associated with moss, microscopic algae and cyanobacteria forms the cascades in the Krka River, resulting in a string of waterfalls and lakes. Tufa samples were collected along streams and lakes and from old tufa deposits outside the present-day watercourse. Several old tufa samples were dated by the $^{230}Th/^{234}U$ method (Horvatinčić et al. 1996). The sequence of tufa samples from Krka River National Park area follows the Krka River flow, from Krčić brook to Prukljan Lake. Samples collected and submitted in 1984 by D Srdoč and

Table 2 Tounj series

Sample nr	Distance from base (cm)	pMC
Z-2429	0–0.3	11.5 ± 0.5
Z-2478	0–1.8	6.0 ± 0.4
Z-2434	1.5–1.8	8.9 ± 0.5
Z-2428	12.0–12.3	3.1 ± 0.7
Z-2477	12.0–13.3	1.2 ± 0.6
Z-2430	13.0–13.3	<0.5
Z-2514	65–66	4.4 ± 0.5

B Obelić, in 1991 by D Srdoč, and 1996 by N Horvatinčić and R. Čalić. Ages of tufa samples from Krčić River were also published in Srdoč et al. (1984, 1987).

A) Krčić Series

Krčić brook empties into the Krka River near the Krka spring close to Knin.

Z-1322. Krčić 1 **36.1 ± 0.8 pMC**
Porous tufa above Krčić brook, right bank, in village of Krčić.

Z-1324. Krčić 2 **0.8 ± 0.7 pMC**
Hard tufa from Jejina Špilja cave, near Krčić brook.

Z-1326. Krčić 3 **0.9 ± 0.5 pMC**
Powdered tufa, ca. 12 m above Krčić brook.

Z-1327. Krčić 4 **0.8 ± 0.5 pMC**
Hard tufa, top of the old tufa outcrop near Krčić brook.

Z-1328. Krčić 5 **7.6 ± 0.5 pMC**
Hard tufa, below Z-1327, same tufa outcrop as above. $^{230}Th/^{234}U$ age 92 ± 4 ka. $\delta^{13}C = -8.8‰$

Z-1329. Krčić 6 **1.3 ± 0.5 pMC**
$\delta^{13}C = -8.7‰$
Hard, porous tufa, below Z-1328, same tufa outcrop as above. $^{230}Th/^{234}U$ age 201 ± 19 ka.

Z-1330. Krčić 7 **6.8 ± 0.7 pMC**
Hard tufa in form of a petrified hollow trunk, same outcrop as above.

B) Topoljski Buk Waterfall Series

Topoljski Buk, a 22-m-high waterfall (also known as Krčić waterfall), Krčić brook, near its mouth in the Krka River; full of water in spring and autumn, and dry in winter and summer. Both recent and old tufa samples were collected at Topoljski Buk waterfall.

Z-1332. Topoljski Buk 1 **57.5 ± 1.0 pMC**
Tufa from barrier, in a tunnel under barrier to Krka River spring.

Z-2360. Topoljski Buk 2 **1.5 ± 0.5 pMC**
Tufa from old barrier. Collected October 1990 and submitted June 1991 by Lj Marjanac, INA-Inženjering, Zagreb.

Comment: (LjM) Tufa barrier covered by younger river and lake sediments.

Z-2552. Topoljski Buk 3 **47.9 ± 0.8 pMC**
Tufa from borehole in barrier. Collected by A Renić, Institute of Geology, Zagreb.

Z-2653. Topoljski Buk 4 **2.6 ± 0.8 pMC**
Hard, crystalline tufa from outcrop near road, close to Topoljski Buk waterfall. $\delta^{13}C = -9.2‰$

Z-2654. Topoljski Buk 5 **59.3 ± 1.1 pMC**
$\delta^{13}C = -9.6‰$

Hard tufa from the top of dry barrier, right side of Topoljski Buk waterfall, inner part of sample.

Z-2673. Topoljski Buk 6 **60.2 ± 1.2 pMC**
Same as above, middle part of sample. $\delta^{13}C = -9.1‰$

Z-2674. Topoljski Buk 7 **60.3 ± 1.2 pMC**
Same as Z-2654, outer part of sample. $\delta^{13}C = -9.5‰$

Z-2655. Topoljski Buk 8 **77.6 ± 1.3 pMC**
Recent tufa from Topoljski Buk waterfall. $\delta^{13}C = -9.7‰$

Z-2656. Topoljski Buk 9 **46.0 ± 1.0 pMC**
Hard tufa, near Z-2654. $\delta^{13}C = -8.8‰$

Z-2657. Topoljski Buk 10 **20.7 ± 0.1 pMC**
Hard tufa, ca. 5 m bellow Z-2654. $\delta^{13}C = -7.3‰$

Z-2658. Topoljski Buk 11 **74.0 ± 1.3 pMC**
Hard tufa from the top of dry barrier. $\delta^{13}C = -7.4‰$

Z-2659. Topoljski Buk 12 **61.0 ± 1.2 pMC**
Hard tufa, ca. 5 m bellow Z-2656. $\delta^{13}C = -8.6‰$

Z-2660. Topoljski Buk 13 **58.8 ± 1.1 pMC**
Hard tufa near Z-2654. $\delta^{13}C = -8.9‰$

C) Topolje Quarry Series

Huge deposits of old tufa near Knin, more than 20 m thick, formerly exploited as building material.

Z-1310. Topolje Quarry 1 **1.4 ± 0.8 pMC**
Compact, layered tufa, west side of quarry. $^{230}Th/^{234}U$ age 251 +29/–24 ka. $\delta^{13}C = -9.0‰$

Z-1312. Topolje Quarry 2 **2.3 ± 0.4 pMC**
Compact tufa, middle layer, east side of quarry.

Z-1314. Topolje Quarry 3 **8.5 ± 0.3 pMC**
Porous tufa with moss structure (*Cratoneurum commutatum),* top of quarry.

Z-1315. Topolje Quarry 4 **3.7 ± 0.4 pMC**
Porous tufa with moss structure, same location as above. Inner part of sample.

Z-2441. Topolje Quarry 5 **5.0 ± 0.4 pMC**
Same as above, outer part of sample.

Z-2597. Topolje Quarry 6 **1.4 ± 0.8 pMC**
Compact layered tufa from the west side of the quarry (cf. Z-1310). $\delta^{13}C = -9.1‰$

Z-1318. Butišnica R. **46.6 ± 0.7 pMC**
Butišnica River, a tributary of the Krka River, Golubić village. Compact tufa eroded at the surface, bridge near hydroelectric power plant.

D) Ćorića Buk Series

Z-2325. Ćorića Buk 1 **78.9 ± 1.2 pMC**
Tufa from Ćorića Buk waterfall, 15.5 m high, artificial lake Brljan.

Z-2326. Ćorića Buk 2 **80.7 ± 1.2 pMC**
Tufa from Ćorića Buk waterfall. $\delta^{13}C = -7.0‰$

E) Manojlovac Series

Recent tufa and wood samples were collected from the Krka River banks and dry riverbed to determine the initial ^{14}C activity of tufa. A stretch of Krka River with several waterfalls and primitive watermills has remained dry since the construction of hydroelectric plant Manojlovac in 1907 (Friganović 1984), enabling us to collect samples that are not contaminated by bomb ^{14}C.

Z-2327. Manojlovac 1 **74.1 ± 0.8 pMC**
Recent tufa from 32-m-high tufa barrier, Manojlovac waterfall

Z-2328. Manojlovac 2 **79.0 ± 1.5 pMC**
Crystalline tufa from barrier above waterfall $\delta^{13}C = -8.0‰$

Z-2329. Manojlovac 3 **90 ± 120**
Wood from Manojlović mill. **99.1 ± 1.4 pMC**

Z-2330. Manojlovac 4 **82.0 ± 1.3 pMC**
Recent porous tufa with moss structure, near Manojlović mill. $\delta^{13}C = -7.2‰$

Z-2397. Manojlovac 5 **85.3 ± 0.8 pMC**
Recent porous dry tufa from Manojlovac waterfall near Kevića mill.

F) Rošnjak Series

Z-2395. Rošnjak 1 **79.5 ± 1.4 pMC**
Tufa from river bed, Krka River between Rošnjak and Miljacka waterfalls. $\delta^{13}C = -8.2‰$

Z-2396. Rošnjak 2 **80.6 ± 0.7 pMC**

Tufa from dry riverbed, Krka River, upstream from Rošnjak waterfall.

Z-2617. Roški slap waterfall **90.6 ± 1.0 pMC**
Recent tufa from Roški slap waterfall, 15 m high. Coll A. Plenković, Faculty of Natural Sciences, Zagreb.

G) Kalića Kuk Series

Old tufa barrier between Lakes Visovac and Mlinarsko, presently 10–15 m above the lake surface.

Comment: (NH) ^{14}C content indicates the degree of contamination with recent carbon.

Z-2647. Kalića Kuk 1 **5.5 ± 0.6 pMC**
Hard, porous tufa, top of the barrier. $\delta^{13}C = -8.0‰$

Z-2648. Kalića Kuk 2 **8.4 ± 0.6 pMC**
Hard, compact tufa, bottom of the barrier, from short tunnel dug into the barrier. $\delta^{13}C = -8.4‰$

Z-2649. Kalića Kuk 3 **9.3 ± 0.8 pMC**
Hard, compact tufa, top of the barrier. $^{230}Th/^{234}U$ age 113 ± 4 ka. $\delta^{13}C = -9.7‰$

Z-2650. Kalića Kuk 4 **2.4 ± 0.6 pMC**
Hard, porous tufa, same location as Z-2648. $^{230}Th/^{234}U$ age 120 ± 9 ka. $\delta^{13}C = -8.9‰$

Z-2651. Kalića Kuk 5 **2.1 ± 0.8 pMC**
Hard, compact tufa, same location as above. $\delta^{13}C = -8.3‰$

Z-2652. Kalića Kuk 6 **1.4 ± 0.6 pMC**
Layered tufa, same location as Z-2648. $^{230}Th/^{234}U$ age 116 ± 6 ka. $\delta^{13}C = -8.7‰$

H) Skradinski Buk Waterfalls Series

The waterfalls on Krka River with the greatest volume of water, consisting of 17 cascades, up to 100 m wide and 400 m of total length. Total height 45.7 m (Friganović 1984).

Z-2661. Skradinski Buk 1 **81.4 ± 1.3 pMC**
Compact tufa, partly porous, from dry barrier, left bank of the Krka River. $\delta^{13}C = -7.7‰$

Z-2662. Skradinski Buk 2 **94.9 ± 1.4 pMC**
Recent, porous tufa covered by moss, below waterfalls, left bank of Krka River. $\delta^{13}C = -9.6‰$

Z-2663. Skradinski Buk 3 **83.6 ± 1.3 pMC**
Hard, porous tufa from dry barrier, above Z-2661. $\delta^{13}C = -8.5‰$

Z-2664. Skradinski Buk 4 **73.8 ± 1.3 pMC**
Compact tufa from dry barrier, above Z-2663. $\delta^{13}C = -9.7‰$

Z-2665. Skradinski Buk 5 **78.2 ± 1.3 pMC**
Recent tufa in tubular form, right bank of the Krka River. $\delta^{13}C = -9.4‰$

Z-2618. Skradinski Buk 6 **80.2 ± 1.3 pMC**
Recent tufa below waterfall, left bank of the Krka River. Collected in 1996 by A Plenković.

I) Lake Prukljan Series

Submerged tufa barrier in Lake Prukljan formed by the Krka River. Collected in 1991 by D Petricioli

Z-2366. Lake Prukljan 1 **105.3 ± 0.8 pMC**
Tufa from submerged barrier, water depth 3.5 m.

Z-2367. Lake Prukljan 2 **103.9 ± 0.7 pMC**
Shells separated from tufa Z-2366.

Plitvice National Park Series

A) Lake Prošće–Matica River Series

Sediment from Lake Prošće at Matica River mouth, 9 m water depth. Collected in August 1990 by D Petricioli and submitted by D Srdoč and N Horvatinčić.

Z-2289. Lake Prošće -Matica 1 **96.2 ± 1.3 pMC**
Sawdust from watermills mixed with lake sediment, 0–6 cm depth.

Z-2290. Lake Prošće - Matica 2 **97.2 ± 1.3 pMC**
Same as above, 6–11 cm depth.

B) Lake Prošće Series

Analyses of shallow sediment cores from Lake Prošće to determine the increase of ^{14}C activity in lake sediment by nuclear bomb effect and local anthropogenic pollution in the uppermost 30 cm thick layers (Srdoč et al. 1992a). The sediments were cored at two different water depths: 20 m and 32 m. Collected Mar. and Aug. 1990 by D Petricioli and submitted by D Srdoč and N Horvatinčić.

Comment: Initial ^{14}C activity of Lake Prošće sediments is 72.0 pMC (Krajcar Bronić et al. 1992). Upper 5–10 cm of sediment was formed after ca. AD 1950.

Table 3 Lake Prošće sediment core

Sample nr	Depth (cm)	$\delta^{13}C$ (‰)	pMC
20 m water depth			
Z-2222	0–5		77.8 ± 0.6
Z-2223	5–10		72.4 ± 1.0
Z-2224	10–15		69.8 ± 1.1
Z-2225	15–20		66.3 ± 1.0
Z-2226	20–23		67.5 ± 1.0
32 m water depth			
Z-2237	1–5	–9.40	79.3 ± 1.1
Z-2275	5–10	–9.47	76.5 ± 0.8
Z-2277	10–15	–9.31	70.6 ± 0.7
Z-2276	15–20	–9.03	69.1 ± 1.1
Z-2278	20–25	–8.97	67.7 ± 1.0
Z-2279	25–29	–9.02	66.7 ± 0.7

Z-2322. Lake Prošće **136.8 ± 1.3 pMC**
$\delta^{13}C = -33.50‰$
Organic residue of sediment after chemical pretreatment of sample Z-2222, 0–5 cm depth.

Comment: Precipitation after AD 1950 is confirmed (Srdoč et al. 1992a).

C) Lake Kozjak Series

Samples from recent sediment cores from Lake Kozjak to determine the increase of ^{14}C activity in lake sediment by nuclear bomb effect, and local anthropogenic pollution in the uppermost 20-cm-thick layers (Srdoč et al. 1992a). Sediments were cored at water depths 21.5 m and 38 m in March and in August 1990 by D Petricioli. Previous measurements: Z-2116 to -2120 (Srdoč et al. 1992b: 170–171).

Comment: Initial ^{14}C activity of Lake Kozjak is 76.0 pMC (Krajcar Bronić et al. 1992). Upper 5–10 cm of sediment precipitated after ca. AD 1950.

Table 4 Lake Kozjak sediment core

Sample nr	Depth (cm)	$\delta^{13}C$ (‰ PDB)	pMC
Core #1, 21.5 m water depth, March 1990			
Z-2233	0–5		88.6 ± 0.8
Z-2234	5–10		74.7 ± 0.7
Z-2235	10–15		72.6 ± 0.7
Z-2236	15–20		71.4 ± 0.5
Core #2, 38 m water depth, August 1990			
Z-2266	1–5	–9.02	89.2 ± 0.8
Z-2267	5–10	–8.88	75.5 ± 0.7
Z-2288	15–20	–9.11	75.2 ± 1.1
Core #3, 21.5 m water depth, August 1990			
Z-2272	1–5		88.2 ± 0.9
Z-2268	5–10		76.9 ± 1.1
Z-2271	10–15		74.3 ± 1.1
Z-2269	15–19	–9.08	73.7 ± 1.1
Z-2270	19–23	–9.11	73.2 ± 0.7
Core #4, 21.5 m water depth, August 1990			
Z-2295	0–1	–8.69	85.8 ± 1.1
Z-2298	1–2	–8.90	89.3 ± 1.2
Z-2299	2–3		91.0 ± 1.2
Z-2305	3–4	–9.03	90.1 ± 1.1
Z-2310	4–5		89.7 ± 1.1
Z-2312	5–7		86.1 ± 1.1
Z-2313	7–9		81.9 ± 0.8
Z-2314	9–11	–8.92	76.8 ± 1.1
Z-2315	11–13		77.0 ± 1.1
Z-2320	21–23.5	–9.16	75.9 ± 1.1
Core #5, 21.5 m water depth, August 1990			
Z-2296	0–1		80.0 ± 1.2
Z-2297	1–2		85.4 ± 1.1
Z-2304	2–4		81.1 ± 1.1
Z-2311	4–5		82.4 ± 1.1

TREE RINGS

Hungary, Mt Matra

Cellulose from spruce tree rings (1956–1986) (*Picea* sp.), Mt Matra, northern Hungary (47°54′N, 19°55′E), 650 m asl. Collected and submitted in July 1987 by K Kozák, Institute of Isotopes, Hungarian Academy of Science, Budapest, Hungary.

Comment: (KK) The tree was felled at the end of the 1986 growing season. Cellulose preparation is described in Kozák et al. (1989). Comparison with other atmospheric and tree-ring ^{14}C data in Krajcar Bronić et al. (1998).

Table 5 Spruce tree rings, Mt Matra

Sample nr	Year	$\Delta^{14}C$ (‰)	$\delta^{13}C$ (‰)
Z-2012	1956	63.8 ± 9.6	−22.0
Z-2013	1959	279.6 ± 14.0	
Z-2014	1961	209.2 ± 12.3	
Z-2015	1963	662.6 ± 20.1	
Z-2049	1964	869.1 ± 19.4	−21.0
Z-2048	1965	750.0 ± 19.2	−21.0
Z-2016	1966	700.7 ± 18.8	
Z-2017	1969	560.0 ± 17.5	
Z-2018	1972	462.5 ± 14.4	
Z-2019	1975	426.1 ± 14.4	
Z-2020	1978	368.2 ± 13.8	
Z-2021	1981	247.6 ± 12.9	
Z-2022	1984	280.2 ± 12.8	
Z-2023	1986	190.4 ± 12.3	−19.9

Croatia, Plitvice Lakes National Park

Cellulose from tree rings (1960–1986) of spruce (*Picea* sp.) from Plitvice National Park. The tree was felled in summer 1987. Collected and submitted 1987 by B Obelić and K Kozák.

Comment: ^{14}C activity in tree rings reflects global atmospheric variation not affected by local industrial CO_2 emissions. ^{14}C activities of tree rings are in good agreement with ^{14}C activities of atmospheric CO_2 (Obelić et al. 1992; Krajcar Bronić et al. 1998) and Mt Matra tree ring ^{14}C activities.

Slovenia, Krško

Linden (*Tilia* sp.) tree rings (1980–1983), from Libna, near Krško (45°55′N, 15°31′E), ca. 180 m asl, ca. 1 km east of the nuclear power plant Krško. The tree was felled in 1984.

Comment: ^{14}C activities of tree rings are in good agreement with the ^{14}C activities of atmospheric CO_2 (Obelić et al. 1992; Krajcar Bronić et al. 1998), as well as with the Mt Matra and Plitvice tree-ring ^{14}C activities.

ACKNOWLEDGMENTS

We thank E Hernaus and D Vošćak for sample preparation. We also thank MA Geyh, Geowissenschaftliche Gemeinschaftsaufgaben, Hannover, Germany, and J Pezdič, Jožef Stefan Institute, Ljubljana, Slovenia for stable isotope measurements.

Table 6 Plitvice tree rings

Sample nr	Year	$\Delta^{14}C$ (‰)
Z-2375	1950	9.1 ± 9.7
Z-2380	1960	352.3 ± 12.9
Z-2194	1961	238.2 ± 12.3
Z-2195	1963	762.6 ± 19.1
Z-2372	1963	756.5 ± 15.7
Z-2196	1964	875.2 ± 18.7
Z-2377	1965	760.9 ± 13.6
Z-2197	1965	738.5 ± 18.9
Z-2198	1966	699.7 ± 16.2
Z-2379	1967	739.1 ± 16.0
Z-2199	1968	591.9 ± 17.4
Z-2394	1969	557.4 ± 18.3
Z-2393	1971	155.7 ± 19.2
Z-2200	1972	497.0 ± 19.9
Z-2376	1973	474.8 ± 10.4
Z-2392	1974	433.8 ± 17.2
Z-2201	1975	399.0 ± 15.2
Z-2402	1976	380.5 ± 16.8
Z-2378	1977	478.3 ± 12.7
Z-2218	1978	134.7 ± 21.4
Z-2373	1979	341.4 ± 11.0
Z-2219	1981	278.0 ± 11.8
Z-2220	1984	238.4 ± 13.7
Z-2221	1986	196.5 ± 19.2
Z-2374	1986	223.3 ± 9.8

Table 7 Libna near Krško tree rings

Sample nr	Year	$\Delta^{14}C$ (‰)
Z-1413	1980	360.7 ± 15.2
Z-1412	1981	258.1 ± 14.8
Z-1411	1982	245.7 ± 14.7
Z-1410	1983	222.8 ± 14.2
Z-1408	Bark (outer layer)	188.0 ± 13.9
Z-1409	Sap wood	325.3 ± 14.6

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